

REMARKS

This Supplemental Amendment follows the Response (filed on May 29, 2001) to the first (nonfinal) Office Action mailed by the USPTO on November 27, 2000. Applicant has added new claims 51-63. Claims 1-63 remain pending in the Application. No new matter has been added to the Application. Reconsideration of the pending claims is respectfully requested.

B

CONCLUSION

It is respectfully submitted that the pending claims 1-63 are in condition for allowance, and such action is respectfully solicited.

Respectfully submitted,

*A. N. Woloch*

Anthony N. Woloch  
Registration No. 30,236

ANW:jjb  
tel: 719-686-6095  
fax: 719-686-6145  
enclosures  
anw\2001\2070700.doc

Claims

I claim:

1. A power module, comprising:
- an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;
  - an electronically-controllable magnetically-latchable air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened position at which the air supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;
  - an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;
  - a combustion cell defining a variable-volume combustion chamber separate from the air compressor chamber, an air intake port, and an exhaust port, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;
  - an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;
  - an intake valve associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port;

28

B

an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and

a power piston positioned in the combustion chamber and operable to move therein between i) an expansion position at which the combustion chamber reaches its maximum volume and ii) a contraction position at which the combustion chamber reaches its minimum volume.

4

A power module, comprising:

an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;

an air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened position at which the air supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume combustion chamber separate from the air compressor chamber, an air intake port, and an exhaust port, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an intake valve associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port;

an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and

a power piston positioned in the combustion chamber and operable to move therein between i) an expansion position at which the combustion chamber reaches its maximum volume and ii) a contraction position at which the combustion chamber reaches its minimum volume, further including an air check valve arranged in fluid communication between said air exit port of the air compressor cell and the air storage chamber, said air check valve operable to allow only one-way fluid flow from the air compressor chamber to the air storage chamber.

<sup>3</sup>  
~~3.~~ A power module, comprising:

an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;

an air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened

30

B

position at which the air supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume combustion chamber separate from the air compressor chamber, an air intake port, and an exhaust port, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an intake valve associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port;

an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and

a power piston positioned in the combustion chamber and operable to move therein between i) an expansion position at which the combustion chamber reaches its maximum volume and ii) a contraction position at which the combustion chamber reaches its minimum volume, wherein said air supply valve is an electronically-controllable two-way valve including a movable magnetically-latchable poppet having an end portion, a return spring operable to bias the poppet towards one

42 position corresponding to the closed position of the air supply valve, and an  
43 opening-direction electrical coil located proximate the end portion of the poppet,  
44 said opening-direction electrical coil selectively operable to electromagnetically pull  
45 the poppet towards another position corresponding to the opened position of the air  
46 supply valve.

47

1 <sup>4</sup>~~4~~ The power module of claim <sup>3</sup>~~3~~, further including an electronic control  
2 unit operable to selectively and independently control the operation of the air supply  
3 valve with digital pulses of electrical current.

4

1 <sup>7</sup>~~5~~ The power module of claim <sup>6</sup>~~4~~, further including an air pressure sensor  
2 operable to sense the pressure of air in the air storage chamber and provide the  
3 electronic control unit with a signal indicative of such pressure, said electronic  
4 control unit operable to move the air supply valve to its opened position in response  
5 to said pressure being below a threshold air pressure, said electronic control unit  
6 operable to move the air supply valve to its closed position in response to said  
7 pressure being at least the threshold air pressure.

8

1 <sup>8</sup>~~6~~ The power module of claim <sup>7</sup>~~5~~, wherein the control unit is operable to  
2 selectively and independently control the operation of the air supply valve in further  
3 response to at least one sensed parameter selected from the group of ambient air  
4 temperature, ambient barometric pressure, inlet air temperature, inlet air pressure,  
5 actuating fluid temperature, actuating fluid pressure, throttle position, power piston  
6 position, engine brake signals, starter inputs, and ignition switch position.

7

1 <sup>2</sup>~~7~~ The power module of claim 1, wherein the air compressor cell and  
2 the combustion cell are integrally formed adjacent one another by a common  
3 housing.

4

1 <sup>9</sup>~~8~~ A power module, comprising:  
2 an air compressor cell defining a variable-volume air compressor chamber,  
3 an air supply port, and an air exit port, said air supply port and air exit port each

4 arranged in fluid communication with the air compressor chamber, said air supply  
5 port adapted to communicate with a source of supply air;

6 an air supply valve associated with the air supply port and selectively  
7 operable to move between i) a closed position at which the air supply valve closes  
8 the air supply port and thereby closes fluid communication between the source of  
9 supply air and the air compressor chamber via the air supply port and ii) an opened  
10 position at which the air supply valve opens the air supply port and thereby opens  
11 fluid communication between the source of supply air and the air compressor  
12 chamber via the air supply port;

13 an air pump piston positioned in the air compressor chamber and operable to  
14 move between i) an expansion position at which the air compressor chamber reaches  
15 its maximum volume and ii) a contraction position at which the air compressor  
16 chamber reaches its minimum volume;

17 a combustion cell defining a variable-volume combustion chamber separate  
18 from the air compressor chamber, an air intake port, and an exhaust port, said air  
19 intake port and exhaust port each arranged in fluid communication with the  
20 combustion chamber;

21 an air storage chamber arranged in fluid communication between the air exit  
22 port of the air compressor cell and the air intake port of the combustion cell;

23 an intake valve associated with the air intake port of the combustion cell and  
24 selectively operable to move between i) a closed position at which the intake valve  
25 closes the air intake port and thereby closes fluid communication between the air  
26 storage chamber and the combustion chamber via the air intake port and ii) an  
27 opened position at which the intake valve opens the air intake port and thereby opens  
28 fluid communication between the air storage chamber and the combustion chamber  
29 via the air intake port;

30 an exhaust valve associated with the exhaust port of the combustion cell and  
31 selectively operable to move between i) a closed position at which the exhaust valve  
32 closes the exhaust port and thereby closes fluid communication between the  
33 combustion chamber and the exhaust port and ii) an opened position at which the  
34 exhaust valve opens the exhaust port and thereby opens fluid communication  
35 between the combustion chamber and the exhaust port; and



36 a power piston positioned in the combustion chamber and operable to move  
37 therein between i) an expansion position at which the combustion chamber reaches  
38 its maximum volume and ii) a contraction position at which the combustion chamber  
39 reaches its minimum volume, wherein the air pump piston and the power piston are  
40 movable by a common drive device.

41

1 <sup>10</sup>~~9~~ The power module of claim <sup>9</sup>~~8~~, wherein said common drive device  
2 includes a rotatable crankshaft.

3

1 <sup>3</sup>~~10~~ The power module of claim 1, further including a direct-injection fuel  
2 injector extending into the combustion chamber and selectively operable to inject  
3 fuel therein.

4

1 11. A power module, comprising:  
2 a turbocharger including an exhaust gas inlet and a compressed air outlet;  
3 an air compressor cell defining a variable-volume air compressor chamber, a  
4 free air supply port adapted to communicate with atmosphere, at least one  
5 turbocharged air supply port arranged in fluid communication with the compressed  
6 air outlet of the turbocharger, and an air exit port, said free air supply port,  
7 turbocharged air supply port, and air exit port each arranged in separate fluid  
8 communication with the air compressor chamber;

9 an electronically-controllable magnetically-latchable free air supply valve  
10 associated with the free air supply port and selectively operable to move between i) a  
11 closed position at which the air supply valve closes the air supply port and thereby  
12 closes fluid communication between atmosphere and the air compressor chamber via  
13 the free air supply port and ii) an opened position at which the free air supply valve  
14 opens the free air supply port and thereby opens fluid communication between  
15 atmosphere and the air compressor chamber via the free air supply port;

16 an electronically-controllable magnetically-latchable turbocharged air supply  
17 valve associated with each turbocharged air supply port and selectively operable to  
18 move between i) a closed position at which the turbocharged air supply valve closes  
19 its respective turbocharged air supply port and thereby closes fluid communication

20 between the compressed air outlet of the turbocharger and the air compressor  
21 chamber via the respective turbocharged air supply port and ii) an opened position at  
22 which the turbocharged air supply valve opens its respective turbocharged air supply  
23 port and thereby opens fluid communication between the compressed air outlet of  
24 the turbocharger and the air compressor chamber via the respective turbocharged air  
25 supply port;

26 an air pump piston positioned in the air compressor chamber and operable to  
27 move between i) an expansion position at which the air compressor chamber reaches  
28 its maximum volume and ii) a contraction position at which the air compressor  
29 chamber reaches its minimum volume;

30 a combustion cell defining a variable-volume combustion chamber separate  
31 from the air compressor chamber, an air intake port, a free exhaust port adapted to  
32 communicate with atmosphere, and at least one drive exhaust port arranged in fluid  
33 communication with the exhaust gas inlet of the turbocharger, said air intake port,  
34 free exhaust port, and drive exhaust port each arranged in separate fluid  
35 communication with the combustion chamber;

36 an air storage chamber arranged in fluid communication between the air exit  
37 port of the air compressor cell and the air intake port of the combustion cell;

38 an intake valve associated with the air intake port of the combustion cell and  
39 selectively operable to move between i) a closed position at which the intake valve  
40 closes the air intake port and thereby closes fluid communication between the air  
41 storage chamber and the combustion chamber via the air intake port and ii) an  
42 opened position at which the intake valve opens the air intake port and thereby opens  
43 fluid communication between the air storage chamber and the combustion chamber  
44 via the air intake port;

45 a free exhaust valve associated with the free exhaust port of the combustion  
46 cell and selectively operable to move between i) a closed position at which the free  
47 exhaust valve closes the free exhaust port and thereby closes fluid communication  
48 between the combustion chamber and atmosphere via the free exhaust port and ii) an  
49 opened position at which the free exhaust valve opens the free exhaust port and  
50 thereby opens fluid communication between the combustion chamber and  
51 atmosphere via the free exhaust port;

52 a drive exhaust valve associated with each drive exhaust port of the  
53 combustion cell and selectively operable to move between i) a closed position at  
54 which the drive exhaust valve closes its respective drive exhaust port and thereby  
55 closes fluid communication between the combustion chamber and the exhaust gas  
56 inlet of the turbocharger via the respective drive exhaust port and ii) an opened  
57 position at which the drive exhaust valve opens its respective drive exhaust port and  
58 thereby opens fluid communication between the combustion chamber and the  
59 exhaust gas inlet of the turbocharger via the respective drive exhaust port; and  
60 a power piston positioned in the combustion chamber and operable to move  
61 therein between i) an expansion position at which the combustion chamber reaches  
62 its maximum volume and ii) a contraction position at which the combustion chamber  
63 reaches its minimum volume.

64  
B7  
1 12. A power module, comprising:

2 an actuating fluid compressor cell defining a variable-volume actuating fluid  
3 compressor chamber and an actuating fluid port arranged in fluid communication  
4 with the actuating fluid compressor chamber, said actuating fluid port adapted to  
5 communicate with a source of actuating fluid;

6 an actuating fluid drain passage;

7 an actuating fluid supply valve arranged in fluid communication between the  
8 source of actuating fluid and the actuating fluid port and selectively operable to  
9 move between i) a closed position at which the supply valve closes fluid  
10 communication between the source of actuating fluid and the actuating fluid  
11 compressor chamber via the actuating fluid port and ii) an opened position at which  
12 the supply valve opens fluid communication between the source of actuating fluid  
13 and the actuating fluid compressor chamber via the actuating fluid port;

14 an actuating fluid pump piston positioned in the actuating fluid compressor  
15 chamber and operable to move therein between i) an expansion position at which  
16 the actuating fluid compressor chamber reaches its maximum volume and ii) a  
17 contraction position at which the actuating fluid compressor chamber reaches its  
18 minimum volume;

36

AR  
4

19 a combustion cell defining a variable-volume combustion chamber, separate  
20 from the actuating fluid compressor chamber, an air intake port, an exhaust port, and  
21 an actuating fluid common rail, said air intake port and exhaust port each arranged in  
22 fluid communication with the combustion chamber;

23 an actuating fluid storage chamber arranged in fluid communication between  
24 the actuating fluid port of the actuating fluid compressor cell and the actuating fluid  
25 common rail;

26 a hydraulically-actuatable intake valve associated with the air intake port of  
27 the combustion cell and having an actuating fluid chamber and a piston portion  
28 positioned in the actuating fluid chamber, said intake valve selectively operable to  
29 move between i) a closed position at which the intake valve closes the air intake port  
30 and thereby closes fluid communication to the combustion chamber via the air intake  
31 port and ii) an opened position at which the intake valve opens the air intake port  
32 and thereby opens fluid communication to the combustion chamber via the air intake  
33 port;

34 an electronically-controllable magnetically-latchable first control valve  
35 arranged in fluid communication between the actuating fluid common rail and the  
36 actuating fluid chamber of the intake valve, said first control valve selectively  
37 operable to move between i) a closed position at which the first control valve closes  
38 fluid communication between the actuating fluid common rail and the actuating fluid  
39 chamber of the intake valve and opens fluid communication between the actuating  
40 fluid drain passage and the actuating fluid chamber of the intake valve thereby  
41 allowing the intake valve to be moved towards its closed position and ii) an opened  
42 position at which the first control valve opens fluid communication between the  
43 actuating fluid common rail and the actuating fluid chamber of the intake valve and  
44 closes fluid communication between the actuating fluid drain passage and the  
45 actuating fluid chamber of the intake valve thereby allowing the intake valve to be  
46 hydraulically moved towards its opened position ;

47 a hydraulically-actuatable exhaust valve associated with the exhaust port of  
48 the combustion cell and having an actuating fluid chamber and a piston portion  
49 positioned in the actuating fluid chamber, said exhaust valve selectively operable to  
50 move between i) a closed position at which the exhaust valve closes the exhaust port

37

B

51 and thereby closes fluid communication between the combustion chamber and the  
52 exhaust port and ii) an opened position at which the exhaust valve opens the exhaust  
53 port and thereby opens fluid communication between the combustion chamber and  
54 the exhaust port;

55 an electronically-controllable magnetically-latchable second control valve  
56 arranged in fluid communication between the actuating fluid common rail and the  
57 actuating fluid chamber of the exhaust valve, said second control valve selectively  
58 operable to move between i) a closed position at which the second control valve  
59 closes fluid communication between the actuating fluid common rail and the  
60 actuating fluid chamber of the exhaust valve and opens fluid communication  
61 between the actuating fluid drain passage and the actuating fluid chamber of the  
62 exhaust valve thereby allowing the exhaust valve to be moved towards its closed  
63 position and ii) an opened position at which the second control valve opens fluid  
64 communication between the actuating fluid common rail and the actuating fluid  
65 chamber of the exhaust valve and closes fluid communication between the actuating  
66 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby  
67 allowing the exhaust valve to be hydraulically moved towards its opened position;  
68 and

69 a power piston positioned in the combustion chamber and operable to move  
70 therein between i) an expansion position at which the combustion chamber reaches  
71 its maximum volume and ii) a contraction position at which the combustion chamber  
72 reaches its minimum volume.  
73

1 13. The power module of claim 12, further including a check valve  
2 arranged in fluid communication between the actuating fluid port of the actuating  
3 fluid compressor cell and the actuating fluid storage chamber, said check valve  
4 operable to allow only one-way fluid flow from the actuating fluid compressor  
5 chamber to the actuating fluid storage chamber.  
6

1 14. The power module of claim 12, wherein said actuating fluid supply  
2 valve includes a digitally-controlled two-way valve including a movable  
3 magnetically-latchable spool having one end portion and an opposite end portion, a

38

B

4 closing-direction electrical coil located proximate the one end portion of the spool,  
5 and an opening-direction electrical coil located proximate the opposite end portion  
6 of the spool, said closing-direction electrical coil selectively operable to  
7 electromagnetically pull the spool towards one state corresponding to the closed  
8 position of the actuating fluid supply valve, said opening-direction electrical coil  
9 selectively operable to electromagnetically pull the spool towards another state  
10 corresponding to the opened position of the actuating fluid supply valve.  
11

1 15. The power module of claim 12, wherein said first and second control  
2 valves each include a digitally-controlled three-way valve including a movable  
3 magnetically-latchable spool having one end portion and an opposite end portion, a  
4 closing-direction electrical coil located proximate the one end portion of the spool,  
5 and an opening-direction electrical coil located proximate the opposite end portion  
6 of the spool, said closing-direction electrical coil selectively operable to  
7 electromagnetically pull the spool towards one state corresponding to the closed  
8 position of the first control valve, said opening-direction electrical coil selectively  
9 operable to electromagnetically pull the spool towards another state corresponding to  
10 the opened position of the first control valve.  
11

1 16. The power module of claim 12, further including an electronic control  
2 unit operable to control the selectable operation of each said electronically-  
3 controllable valves.  
4

1 17. The power module of claim 16, further including an actuating fluid  
2 pressure sensor operable to i) sense the pressure of actuating fluid in the actuating  
3 fluid storage chamber and ii) provide the electronic control unit with an actuating  
4 fluid pressure signal indicative of said pressure, said electronic control unit operable  
5 to independently control the operation of the actuating fluid supply valve in response  
6 to said actuating fluid pressure signal.  
7

1 18. The power module of claim 16, further including an actuating fluid

2 pressure sensor operable to i) sense the pressure of actuating fluid in the actuating  
3 fluid common rail and ii) provide the electronic control unit with an actuating fluid  
4 pressure signal indicative of said pressure, said electronic control unit operable to  
5 independently control the operation of the first and second control valves in response  
6 to said actuating fluid pressure signal.

7  
1 19. The power module of claim 16, wherein said electronic control unit  
2 further independently controls the operation of the first and second control valves in  
3 response to at least one sensed parameter selected from the group of ambient air  
4 temperature, ambient barometric pressure, inlet air temperature, inlet air pressure,  
5 actuating fluid temperature, actuating fluid pressure, throttle position, power piston  
6 position, engine brake signals, starter inputs, and ignition switch position.

7  
1 20. The power module of claim 12, further including an  
2 electronically-controllable hydraulically-actuatable fuel injector extending into the  
3 combustion chamber and selectively operable to inject fuel therein.  
4

5  
1 21. The power module of claim 20, wherein said injector includes an  
2 actuating fluid chamber, a piston portion positioned in the actuating fluid chamber, a  
3 check valve movable between a closed position at which the check valve blocks  
4 injection of fuel and an opened position at which the check valve opens injection of  
5 fuel, and an electronically-controllable magnetically-latchable third control valve  
6 arranged in fluid communication between the actuating fluid common rail and the  
7 actuating fluid chamber of the injector, said third control valve selectively operable  
8 to move between i) a closed position at which the third control valve closes fluid  
9 communication between the actuating fluid common rail and the actuating fluid  
10 chamber of the injector and opens fluid communication between the actuating fluid  
11 drain passage and the actuating fluid chamber of the injector thereby allowing the  
12 check valve of the injector to be moved towards its closed position and ii) an opened  
13 position at which the third control valve opens fluid communication between the  
14 actuating fluid common rail and the actuating fluid chamber of the injector and  
15 closes fluid communication between the actuating fluid drain passage and the

40

B

16     . actuating fluid chamber of the injector thereby allowing the check valve to be  
17     hydraulically moved towards its opened position.  
18

1             22.     The power module of claim 21, wherein said injector is a multiple  
2     stage injector.  
3

1             23.     The power module of claim 12, wherein said actuating fluid storage  
2     chamber is integrally formed with the actuating fluid compressor cell.  
3

B<sup>8</sup>  
1             24.     The power module of claim 12, wherein said actuating fluid storage  
2     chamber is connected to the actuating fluid compressor cell.  
3

1             25.     The power module of claim 12, wherein said intake and exhaust  
2     valves each further include a return spring operable to bias the respective valve  
3     towards its closed position.  
4

1             26.     The power module of claim 12, wherein the actuating fluid  
2     compressor cell and the combustion cell are integrally formed with one another by a  
3     common housing.  
4

1             27.     The power module of claim 12, wherein the actuating fluid  
2     compressor cell and the combustion cell are connected together as a compact unit.  
3

1             28.     The power module of claim 12, wherein the actuating fluid pump  
2     piston and the power piston are movable by a common drive device.  
3

B<sup>9</sup>  
1             29.     A power module, comprising:  
2             an air compressor cell defining a variable-volume air compressor chamber,  
3     an air supply port, and an air exit port, said air supply port and air exit port each  
4     arranged in fluid communication with the air compressor chamber, said air supply  
5     port adapted to communicate with a source of supply air;

41

B



an air supply valve associated with the air supply port and selectively operable to move between i) a closed position at which the air supply valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port and ii) an opened position at which the supply valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume combustion chamber, separate from the actuating fluid compressor chamber, an air intake port, an exhaust port, and an actuating fluid common rail, said air intake port and exhaust port each arranged in fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an air check valve arranged in fluid communication between said air exit port and the air storage chamber, said air check valve operable to allow only one-way fluid flow from the air compressor chamber to the air storage chamber;

an actuating fluid compressor cell defining a variable-volume actuating fluid compressor chamber and an actuating fluid port arranged in fluid communication with the actuating fluid compressor chamber, said actuating fluid port adapted to communicate with a source of actuating fluid;

an actuating fluid drain passage;

an actuating fluid supply valve arranged in fluid communication between the source of actuating fluid and the actuating fluid port and selectively operable to move between i) a closed position at which the supply valve closes fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port and ii) an opened position at which the supply valve opens fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port;

38 an actuating fluid pump piston positioned in the actuating fluid compressor  
39 chamber and operable to move therein between i) an expansion position at which  
40 the actuating fluid compressor chamber reaches its maximum volume and ii) a  
41 contraction position at which the actuating fluid compressor chamber reaches its  
42 minimum volume;

43 an actuating fluid storage chamber arranged in fluid communication between  
44 the actuating fluid port of the actuating fluid compressor cell and the actuating fluid  
45 common rail;

46 an actuating fluid check valve arranged in fluid communication between the  
47 actuating fluid port of the actuating fluid compressor cell and the actuating fluid  
48 storage chamber, said actuating fluid check valve operable to allow only one-way  
49 fluid flow from the actuating fluid compressor chamber to the actuating fluid storage  
50 chamber;

51 a hydraulically-actuatable intake valve associated with the air intake port of  
52 the combustion cell and having an actuating fluid chamber and a piston portion  
53 positioned in the actuating fluid chamber, said intake valve selectively operable to  
54 move between i) a closed position at which the intake valve closes the air intake port  
55 and thereby closes fluid communication between the air storage chamber and the  
56 combustion chamber via the air intake port and ii) an opened position at which the  
57 intake valve opens the air intake port and thereby opens fluid communication  
58 between the air storage chamber and the combustion chamber via the air intake port;

59 an electronically-controllable magnetically-latchable first control valve  
60 arranged in fluid communication between the actuating fluid common rail and the  
61 actuating fluid chamber of the intake valve, said first control valve selectively  
62 operable to move between i) a closed position at which the first control valve closes  
63 fluid communication between the actuating fluid common rail and the actuating fluid  
64 chamber of the intake valve and opens fluid communication between the actuating  
65 fluid drain passage and the actuating fluid chamber of the intake valve thereby  
66 allowing the intake valve to be moved towards its closed position and ii) an opened  
67 position at which the first control valve opens fluid communication between the  
68 actuating fluid common rail and the actuating fluid chamber of the intake valve and  
69 closes fluid communication between the actuating fluid drain passage and the

70 actuating fluid chamber of the intake valve thereby allowing the intake valve to be  
71 hydraulically moved towards its opened position ;

72 a hydraulically-actuatable exhaust valve associated with the exhaust port of  
73 the combustion cell and having an actuating fluid chamber and a piston portion  
74 positioned in the actuating fluid chamber, said exhaust valve selectively operable to  
75 move between i) a closed position at which the exhaust valve closes the exhaust port  
76 and thereby closes fluid communication between the combustion chamber and the  
77 exhaust port and ii) an opened position at which the exhaust valve opens the exhaust  
78 port and thereby opens fluid communication between the combustion chamber and  
79 the exhaust port;

80 an electronically-controllable magnetically-latchable second control valve  
81 arranged in fluid communication between the actuating fluid common rail and the  
82 actuating fluid chamber of the exhaust valve, said second control valve selectively  
83 operable to move between i) a closed position at which the second control valve  
84 closes fluid communication between the actuating fluid common rail and the  
85 actuating fluid chamber of the exhaust valve and opens fluid communication  
86 between the actuating fluid drain passage and the actuating fluid chamber of the  
87 exhaust valve thereby allowing the exhaust valve to be moved towards its closed  
88 position and ii) an opened position at which the second control valve opens fluid  
89 communication between the actuating fluid common rail and the actuating fluid  
90 chamber of the exhaust valve and closes fluid communication between the actuating  
91 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby  
92 allowing the exhaust valve to be hydraulically moved towards its opened position;  
93 and

94 a power piston positioned in the combustion chamber and operable to move  
95 therein between i) an expansion position at which the combustion chamber reaches  
96 its maximum volume and ii) a contraction position at which the combustion chamber  
97 reaches its minimum volume.  
98

1 30. The power module of claim 29, wherein said actuating fluid pump  
2 piston is driven by said air pump piston.  
3

31. A power module, comprising:

B11  
an air compressor cell defining a variable-volume air compressor chamber, an air supply port, and an air exit port, said air supply port and air exit port each arranged in separate fluid communication with the air compressor chamber, said air supply port adapted to communicate with a source of supply air;

an electronically-controllable magnetically-latchable air supply poppet valve associated with the air supply port, said air supply poppet valve including a magnetically-latchable poppet having an end portion and movable between a closed position and an opened position, a return spring operable to bias the poppet of the air supply poppet valve towards its closed position at which the poppet of the air supply poppet valve closes the air supply port and thereby closes fluid communication between the source of supply air and the air compressor chamber via the air supply port, and an opening-direction electrical coil located proximate the end portion of the poppet, said opening-direction electrical coil selectively operable to electromagnetically pull the poppet of the air supply poppet valve towards its opened position at which the poppet of the air supply poppet valve opens the air supply port and thereby opens fluid communication between the source of supply air and the air compressor chamber via the air supply port;

an air pump piston positioned in the air compressor chamber and operable to reciprocally move between i) an expansion position at which the air compressor chamber reaches its maximum volume and ii) a contraction position at which the air compressor chamber reaches its minimum volume;

a combustion cell defining a variable-volume internal combustion chamber, separate from the actuating fluid compressor chamber, an air intake port, an exhaust port, and an actuating fluid common rail, said air intake port and exhaust port each arranged in separate fluid communication with the combustion chamber;

an air storage chamber arranged in fluid communication between the air exit port of the air compressor cell and the air intake port of the combustion cell;

an air check valve arranged in fluid communication between said air exit port and the air storage chamber, said air check valve operable to allow only one-way fluid flow from the air compressor chamber to the air storage chamber;

an actuating fluid compressor cell defining a variable-volume actuating fluid compressor chamber and an actuating fluid port arranged in fluid communication with the actuating fluid compressor chamber, said actuating fluid port adapted to communicate with a source of actuating fluid;

an actuating fluid drain passage;

B'  
an electronically-controllable magnetically-latchable two-way actuating fluid supply valve arranged in fluid communication between the source of actuating fluid and the actuating fluid port, said actuating fluid supply valve including a magnetically-latchable spool having one end portion and an opposite end portion and movable between a closed position and an opened position, a closing-direction electrical coil located proximate the one end portion of the spool, and an opening-direction electrical coil located proximate the opposite end portion of the spool, said closing-direction electrical coil selectively operable to electromagnetically pull the spool of the actuating fluid supply valve towards its closed position at which the spool of the actuating fluid supply valve closes fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port, said opening-direction electrical coil selectively operable to electromagnetically pull the spool of the actuating fluid supply valve towards its opened position at which the spool of the actuating fluid supply valve opens fluid communication between the source of actuating fluid and the actuating fluid compressor chamber via the actuating fluid port;

an actuating fluid pump piston positioned in the actuating fluid compressor chamber and operable to reciprocally move therein between i) an expansion position at which the actuating fluid compressor chamber reaches its maximum volume and ii) a contraction position at which the actuating fluid compressor chamber reaches its minimum volume;

an actuating fluid storage chamber arranged in fluid communication between the actuating fluid port of the actuating fluid compressor cell and the actuating fluid common rail;

an actuating fluid check valve arranged in fluid communication between the actuating fluid port of the actuating fluid compressor cell and the actuating fluid storage chamber, said actuating fluid check valve operable to allow only one-way

46

\$

64 fluid flow from the actuating fluid compressor chamber to the actuating fluid storage  
65 chamber;

66 a hydraulically-actuatable intake poppet valve associated with the air intake  
67 port of the combustion cell and having an actuating fluid chamber and a piston  
68 portion positioned in the actuating fluid chamber, said intake poppet valve  
69 selectively operable to reciprocally move between i) a closed position at which the  
70 intake poppet valve closes the air intake port and thereby closes fluid  
71 communication between the air storage chamber and the combustion chamber via  
72 the air intake port and ii) an opened position at which the intake poppet valve opens  
73 the air intake port and thereby opens fluid communication between the air storage  
74 chamber and the combustion chamber via the air intake port;

0" 75 an electronically-controllable magnetically-latchable three-way first control  
76 valve arranged in fluid communication between the actuating fluid common rail and  
77 the actuating fluid chamber of the intake valve, said first control valve including a  
78 magnetically-latchable spool having one end portion and an opposite end portion and  
79 movable between a closed position and an opened position, a closing-direction  
80 electrical coil located proximate the one end portion of the spool, and an opening-  
81 direction electrical coil located proximate the opposite end portion of the spool, said  
82 closing-direction electrical coil selectively operable to electromagnetically pull the  
83 spool towards its closed position at which the spool of the first control valve closes  
84 fluid communication between the actuating fluid common rail and the actuating fluid  
85 chamber of the intake poppet valve and opens fluid communication between the  
86 actuating fluid drain passage and the actuating fluid chamber of the intake poppet  
87 valve thereby allowing the intake poppet valve to be moved towards its closed  
88 position, said opening-direction electrical coil selectively operable to  
89 electromagnetically pull the spool towards its opened position at which the spool of  
90 the first control valve opens fluid communication between the actuating fluid  
91 common rail and the actuating fluid chamber of the intake poppet valve and closes  
92 fluid communication between the actuating fluid drain passage and the actuating  
93 fluid chamber of the intake poppet valve thereby allowing the intake poppet valve to  
94 be hydraulically moved towards its opened position;

95 a hydraulically-actuatable exhaust poppet valve associated with the exhaust  
96 port of the combustion cell and having an actuating fluid chamber and a piston  
97 portion positioned in the actuating fluid chamber, said exhaust poppet valve  
98 selectively operable to reciprocally move between i) a closed position at which the  
99 exhaust poppet valve closes the exhaust port and thereby closes fluid communication  
100 between the combustion chamber and the exhaust port and ii) an opened position at  
101 which the exhaust poppet valve opens the exhaust port and thereby opens fluid  
102 communication between the combustion chamber and the exhaust port;

103 an electronically-controllable magnetically-latchable three-way second  
104 control valve arranged in fluid communication between the actuating fluid common  
105 rail and the actuating fluid chamber of the exhaust poppet valve, said second control  
106 valve including a magnetically-latchable spool having one end portion and an  
107 opposite end portion and movable between a closed position and an opened position,  
108 a closing-direction electrical coil located proximate the one end portion of the spool,  
109 and an opening-direction electrical coil located proximate the opposite end portion  
110 of the spool, said closing-direction electrical coil selectively operable to  
111 electromagnetically pull the spool towards its closed position at which the spool of  
112 the second control valve closes fluid communication between the actuating fluid  
113 common rail and the actuating fluid chamber of the exhaust poppet valve and opens  
114 fluid communication between the actuating fluid drain passage and the actuating  
115 fluid chamber of the exhaust poppet valve thereby allowing the exhaust poppet valve  
116 to be moved towards its closed position, said opening-direction electrical coil  
117 selectively operable to electromagnetically pull the spool towards its opened position  
118 at which the spool of the second control valve opens fluid communication between  
119 the actuating fluid common rail and the actuating fluid chamber of the exhaust  
120 poppet valve and closes fluid communication between the actuating fluid drain  
121 passage and the actuating fluid chamber of the exhaust poppet valve thereby  
122 allowing the exhaust poppet valve to be hydraulically moved towards its opened  
123 position; and

124 a power piston positioned in the combustion chamber and operable to  
125 reciprocally move therein between i) an expansion position at which the combustion

48

B

126 chamber reaches its maximum volume and ii) a contraction position at which the  
127 combustion chamber reaches its minimum volume.

128

1 32. An internal combustion engine, comprising:

2 a plurality of power modules connected to generate work together wherein  
3 each power module separately includes an air compressor cell defining a variable-  
4 volume air compressor chamber, an air supply port, and an air exit port, said air  
5 supply port and air exit port each arranged in fluid communication with the air  
6 compressor chamber, said air supply port adapted to communicate with a source of  
7 supply air; an electronically-controllable magnetically-latchable air supply valve  
8 associated with the air supply port and selectively operable to move between i) a  
9 closed position at which the air supply valve closes the air supply port and thereby  
10 closes fluid communication between the source of supply air and the air compressor  
11 chamber via the air supply port and ii) an opened position at which the air supply  
12 valve opens the air supply port and thereby opens fluid communication between the  
13 source of supply air and the air compressor chamber via the air supply port; an air  
14 pump piston positioned in the air compressor chamber and operable to move  
15 between i) an expansion position at which the air compressor chamber reaches its  
16 maximum volume and ii) a contraction position at which the air compressor chamber  
17 reaches its minimum volume; a combustion cell defining a variable-volume  
18 combustion chamber separate from the air compressor chamber, an air intake port,  
19 an exhaust port, and an actuating fluid common rail adapted to be arranged in fluid  
20 communication with a source of pressurized actuating fluid, said air intake port and  
21 exhaust port each arranged in fluid communication with the combustion chamber; an  
22 actuating fluid drain passage; an air storage chamber arranged in fluid  
23 communication between the air exit port of the air compressor cell and the air intake  
24 port of the combustion cell; a hydraulically-actuatable intake valve associated with  
25 the air intake port of the combustion cell and having an actuating fluid chamber and  
26 a piston portion positioned in the acting fluid chamber, said intake valve selectively  
27 operable to move between i) a closed position at which the intake valve closes the air  
28 intake port and thereby closes fluid communication between the air storage chamber  
29 and the combustion chamber via the air intake port and ii) an opened position at



30 which the intake valve opens the air intake port and thereby opens fluid  
31 communication between the air storage chamber and the combustion chamber via  
32 the air intake port; an electronically-controllable magnetically-latchable first control  
33 valve arranged in fluid communication between the actuating fluid common rail and  
34 the actuating fluid chamber of the intake valve, said first control valve selectively  
35 operable to move between i) a closed position at which the first control valve closes  
36 fluid communication between the actuating fluid common rail and the actuating fluid  
37 chamber of the intake valve and opens fluid communication between the actuating  
38 fluid drain passage and the actuating fluid chamber of the intake valve thereby  
39 allowing the intake valve to be moved towards its closed position and ii) an opened  
40 position at which the first control valve opens fluid communication between the  
41 actuating fluid common rail and the actuating fluid chamber of the intake valve and  
42 closes fluid communication between the actuating fluid drain passage and the  
43 actuating fluid chamber of the intake valve thereby allowing the intake valve to be  
44 hydraulically moved towards its opened position; a hydraulically-actuatable exhaust  
45 valve associated with the exhaust port of the combustion cell and having an  
46 actuating fluid chamber and a piston portion positioned in the actuating fluid  
47 chamber, said exhaust valve selectively operable to move between i) a closed  
48 position at which the exhaust valve closes the exhaust port and thereby closes fluid  
49 communication between the combustion chamber and the exhaust port and ii) an  
50 opened position at which the exhaust valve opens the exhaust port and thereby opens  
51 fluid communication between the combustion chamber and the exhaust port; an  
52 electronically-controllable magnetically-latchable second control valve arranged in  
53 fluid communication between the actuating fluid common rail and the actuating fluid  
54 chamber of the exhaust valve, said second control valve selectively operable to move  
55 between i) a closed position at which the second control valve closes fluid  
56 communication between the actuating fluid common rail and the actuating fluid  
57 chamber of the exhaust valve and opens fluid communication between the actuating  
58 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby  
59 allowing the exhaust valve to be moved towards its closed position and ii) an opened  
60 position at which the second control valve opens fluid communication between the  
61 actuating fluid common rail and the actuating fluid chamber of the exhaust valve and

50

B

62 closes fluid communication between the actuating fluid drain passage and the  
63 actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to  
64 be hydraulically moved towards its opened position; and a power piston positioned  
65 in the respective combustion chamber and operable to move therein between i) an  
66 expansion position at which the respective combustion chamber reaches its  
67 maximum volume and ii) a contraction position at which the respective combustion  
68 chamber reaches its minimum volume; wherein said air compressor chamber and air  
69 storage chamber of each power module are isolated from fluid communication and  
70 independently operable with respect to the air compressor chamber and air storage  
71 chamber of any other said power module of the internal combustion engine.

36  
~~33~~

An internal combustion engine, comprising:

8" 2 a plurality of power modules connected to generate work together wherein  
3 each power module separately includes an air compressor cell defining a variable-  
4 volume air compressor chamber, an air supply port, and an air exit port, said air  
5 supply port and air exit port each arranged in fluid communication with the air  
6 compressor chamber, said air supply port adapted to communicate with a source of  
7 supply air; an air supply valve associated with the air supply port and selectively  
8 operable to move between i) a closed position at which the air supply valve closes  
9 the air supply port and thereby closes fluid communication between the source of  
10 supply air and the air compressor chamber via the air supply port and ii) an opened  
11 position at which the air supply valve opens the air supply port and thereby opens  
12 fluid communication between the source of supply air and the air compressor  
13 chamber via the air supply port; an air pump piston positioned in the air compressor  
14 chamber and operable to move between i) an expansion position at which the air  
15 compressor chamber reaches its maximum volume and ii) a contraction position at  
16 which the air compressor chamber reaches its minimum volume; a combustion cell  
17 defining a variable-volume combustion chamber separate from the air compressor  
18 chamber, an air intake port, and an exhaust port, said air intake port and exhaust port  
19 each arranged in fluid communication with the combustion chamber; an air storage  
20 chamber arranged in fluid communication between the air exit port of the air  
21 compressor cell and the air intake port of the combustion cell; an intake valve

51

B

associated with the air intake port of the combustion cell and selectively operable to move between i) a closed position at which the intake valve closes the air intake port and thereby closes fluid communication between the air storage chamber and the combustion chamber via the air intake port and ii) an opened position at which the intake valve opens the air intake port and thereby opens fluid communication between the air storage chamber and the combustion chamber via the air intake port; an exhaust valve associated with the exhaust port of the combustion cell and selectively operable to move between i) a closed position at which the exhaust valve closes the exhaust port and thereby closes fluid communication between the combustion chamber and the exhaust port and ii) an opened position at which the exhaust valve opens the exhaust port and thereby opens fluid communication between the combustion chamber and the exhaust port; and a power piston positioned in the respective combustion chamber and operable to move therein between i) an expansion position at which the respective combustion chamber reaches its maximum volume and ii) a contraction position at which the respective combustion chamber reaches its minimum volume; wherein said air compressor chamber and air storage chamber of each power module are isolated from fluid communication and independently operable with respect to the air compressor chamber and air storage chamber of any other said power module of the internal combustion engine, further including a separate electronic control unit associated with each power module, each electronic control unit operable to selectively and independently control the operation of the respective air supply valve with digital pulses of electrical current.

<sup>37</sup>  
~~34~~ The internal combustion engine of claim <sup>36</sup>~~33~~, further including an air pressure sensor associated with each power module, said air pressure sensor operable to sense the pressure of air in the respective air storage chamber and provide the respective electronic control unit with a signal indicative of such pressure, said respective electronic control unit operable to move the respective air supply valve to its opened position in response to said pressure being below a threshold air pressure, said respective electronic control unit operable to move the respective air supply

012  
8 valve to its closed position in response to said pressure being at least the threshold  
9 air pressure.  
10

38  
35. An internal combustion engine, comprising:

013  
1 a plurality of power modules connected to generate work together wherein  
2 each power module separately includes an air compressor cell defining a variable-  
3 volume air compressor chamber, an air supply port, and an air exit port, said air  
4 supply port and air exit port each arranged in fluid communication with the air  
5 compressor chamber, said air supply port adapted to communicate with a source of  
6 supply air; an air supply valve associated with the air supply port and selectively  
7 operable to move between i) a closed position at which the air supply valve closes  
8 the air supply port and thereby closes fluid communication between the source of  
9 supply air and the air compressor chamber via the air supply port and ii) an opened  
10 position at which the air supply valve opens the air supply port and thereby opens  
11 fluid communication between the source of supply air and the air compressor  
12 chamber via the air supply port; an air pump piston positioned in the air compressor  
13 chamber and operable to move between i) an expansion position at which the air  
14 compressor chamber reaches its maximum volume and ii) a contraction position at  
15 which the air compressor chamber reaches its minimum volume; a combustion cell  
16 defining a variable-volume combustion chamber separate from the air compressor  
17 chamber, an air intake port, and an exhaust port, said air intake port and exhaust port  
18 each arranged in fluid communication with the combustion chamber; an air storage  
19 chamber arranged in fluid communication between the air exit port of the air  
20 compressor cell and the air intake port of the combustion cell; an intake valve  
21 associated with the air intake port of the combustion cell and selectively operable to  
22 move between i) a closed position at which the intake valve closes the air intake port  
23 and thereby closes fluid communication between the air storage chamber and the  
24 combustion chamber via the air intake port and ii) an opened position at which the  
25 intake valve opens the air intake port and thereby opens fluid communication  
26 between the air storage chamber and the combustion chamber via the air intake port;  
27 an exhaust valve associated with the exhaust port of the combustion cell and  
28 selectively operable to move between i) a closed position at which the exhaust valve  
29

53

B

B13

30 closes the exhaust port and thereby closes fluid communication between the  
31 combustion chamber and the exhaust port and ii) an opened position at which the  
32 exhaust valve opens the exhaust port and thereby opens fluid communication  
33 between the combustion chamber and the exhaust port; and a power piston  
34 positioned in the respective combustion chamber and operable to move therein  
35 between i) an expansion position at which the respective combustion chamber  
36 reaches its maximum volume and ii) a contraction position at which the respective  
37 combustion chamber reaches its minimum volume; wherein said air compressor  
38 chamber and air storage chamber of each power module are isolated from fluid  
39 communication and independently operable with respect to the air compressor  
40 chamber and air storage chamber of any other said power module of the internal  
41 combustion engine, wherein each control unit is operable to selectively and  
42 independently control the operation of the respective air supply valve in response to  
43 at least one sensed parameter selected from the group of air temperature, air  
44 manifold pressure, actuating fluid temperature, actuating fluid pressure, barometric  
45 pressure, throttle position, power piston position, engine brake signals, starter inputs,  
46 and ignition switch position.

B14

33  
36. The internal combustion engine of claim 32, wherein the air  
compressor cell and combustion cell of each power module are located adjacent to  
one another.

34  
37. The internal combustion engine of claim 32, wherein said power  
modules are arranged substantially in-line relative to one another.

35  
38. The internal combustion engine of claim 32, wherein the air  
compressor cells are arranged in an alternating and substantially in-line pattern with  
respect to the combustion cells.

P15

39. An internal combustion engine, comprising:  
a plurality of power modules connected to generate work together wherein each  
power module separately includes an actuating fluid compressor cell defining a

4 variable-volume actuating fluid compressor chamber and an actuating fluid port  
5 arranged in fluid communication with the actuating fluid compressor chamber, said  
6 actuating fluid port adapted to communicate with a source of actuating fluid; an  
7 actuating fluid drain passage; an actuating fluid supply valve arranged in fluid  
8 communication between the source of actuating fluid and the actuating fluid port and  
9 selectively operable to move between i) a closed position at which the supply valve  
10 closes fluid communication between the source of actuating fluid and the actuating  
11 fluid compressor chamber via the actuating fluid port and ii) an opened position at  
12 which the supply valve opens fluid communication between the source of actuating  
13 fluid and the actuating fluid compressor chamber via the actuating fluid port; an  
14 actuating fluid pump piston positioned in the actuating fluid compressor chamber  
15 and operable to move therein between i) an expansion position at which the  
16 actuating fluid compressor chamber reaches its maximum volume and ii) a  
17 contraction position at which the actuating fluid compressor chamber reaches its  
18 minimum volume; a combustion cell defining a variable-volume combustion  
19 chamber, separate from the actuating fluid compressor chamber, an air intake port,  
20 an exhaust port, and an actuating fluid common rail, said air intake port and exhaust  
21 port each arranged in fluid communication with the combustion chamber; an  
22 actuating fluid storage chamber arranged in fluid communication between the  
23 actuating fluid port of the actuating fluid compressor cell and the actuating fluid  
24 common rail; a hydraulically-actuatable intake valve associated with the air intake  
25 port of the combustion cell and having an actuating fluid chamber and a piston  
26 portion positioned in the actuating fluid chamber, said intake valve selectively  
27 operable to move between i) a closed position at which the intake valve closes the air  
28 intake port and thereby closes fluid communication between the air storage chamber  
29 and the combustion chamber via the air intake port and ii) an opened position at  
30 which the intake valve opens the air intake port and thereby opens fluid  
31 communication between the air storage chamber and the combustion chamber via  
32 the air intake port; an electronically-controllable magnetically-latchable first control  
33 valve arranged in fluid communication between the actuating fluid common rail and  
34 the actuating fluid chamber of the intake valve, said first control valve selectively  
35 operable to move between i) a closed position at which the first control valve closes

55

B

36 fluid communication between the actuating fluid common rail and the actuating fluid  
37 chamber of the intake valve and opens fluid communication between the actuating  
38 fluid drain passage and the actuating fluid chamber of the intake valve thereby  
39 allowing the intake valve to be moved towards its closed position and ii) an opened  
40 position at which the first control valve opens fluid communication between the  
41 actuating fluid common rail and the actuating fluid chamber of the intake valve and  
42 closes fluid communication between the actuating fluid drain passage and the  
43 actuating fluid chamber of the intake valve thereby allowing the intake valve to be  
44 hydraulically moved towards its opened position; a hydraulically-actuatable exhaust  
45 valve associated with the exhaust port of the combustion cell and having an  
46 actuating fluid chamber and a piston portion positioned in the actuating fluid  
47 chamber, said exhaust valve selectively operable to move between i) a closed  
48 position at which the exhaust valve closes the exhaust port and thereby closes fluid  
49 communication between the combustion chamber and the exhaust port and ii) an  
50 opened position at which the exhaust valve opens the exhaust port and thereby opens  
51 fluid communication between the combustion chamber and the exhaust port; an  
52 electronically-controllable magnetically-latchable second control valve arranged in  
53 fluid communication between the actuating fluid common rail and the actuating fluid  
54 chamber of the exhaust valve, said second control valve selectively operable to move  
55 between i) a closed position at which the second control valve closes fluid  
56 communication between the actuating fluid common rail and the actuating fluid  
57 chamber of the exhaust valve and opens fluid communication between the actuating  
58 fluid drain passage and the actuating fluid chamber of the exhaust valve thereby  
59 allowing the exhaust valve to be moved towards its closed position and ii) an opened  
60 position at which the second control valve opens fluid communication between the  
61 actuating fluid common rail and the actuating fluid chamber of the exhaust valve and  
62 closes fluid communication between the actuating fluid drain passage and the  
63 actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to  
64 be hydraulically moved towards its opened position; and a power piston positioned  
65 in the combustion chamber and operable to move therein between i) an expansion  
66 position at which the combustion chamber reaches its maximum volume and ii) a  
67 contraction position at which the combustion chamber reaches its minimum volume;

56

B

B'5  
68 wherein said actuating fluid compressor chamber and actuating fluid storage  
69 chamber of each power module are isolated from fluid communication and  
70 independently operable with respect to the actuating fluid compressor chamber and  
71 actuating fluid storage chamber of any other said power module of the internal  
72 combustion engine.  
73

1 40. The internal combustion engine of claim 39, wherein said  
2 actuating fluid compressor cell and combustion cell of each power module are  
3 located adjacent to one another.  
4

B'6  
1 41. The internal combustion engine of claim 39, wherein said power  
2 modules are arranged substantially in-line relative to one another.  
3

1 42. The internal combustion engine of claim 39, wherein the actuating  
2 fluid compressor cells are arranged in an alternating and substantially in-line pattern  
3 with respect to the combustion cells.  
4

B'7  
1 43. A two-stroke cycle power module, comprising:  
2 a rotatable crankshaft;  
3 a combustion chamber;  
4 an actuating fluid drain passage;  
5 an actuating fluid common rail adapted to be arranged in fluid  
6 communication with a source of pressurized actuating fluid;  
7 a movable power piston positioned in the combustion chamber and  
8 coupled to the crankshaft for movement therewith;  
9 an electronically-controllable hydraulically-actuatable intake valve having an  
10 actuating fluid chamber and a piston portion positioned in the actuating fluid  
11 chamber, said intake valve selectively operable to admit air into the combustion  
12 chamber;  
13 an electronically-controllable magnetically-latchable first control valve  
14 arranged in fluid communication between the actuating fluid common rail and the  
15 actuating fluid chamber of the intake valve, said first control valve selectively



operable to move between i) a closed position at which the first control valve closes fluid communication between the actuating fluid common rail and the actuating fluid chamber of the intake valve and opens fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the intake valve thereby allowing the intake valve to be moved towards its closed position and ii) an opened position at which the first control valve opens fluid communication between the actuating fluid common rail and the actuating fluid chamber of the intake valve and closes fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the intake valve thereby allowing the intake valve to be hydraulically moved towards its opened position;

an electronically-controllable hydraulically-actuatable exhaust valve having an actuating fluid chamber and a piston portion positioned in the actuating fluid chamber, said exhaust valve selectively operable to vent exhaust gas from the combustion chamber;

517 an electronically-controllable magnetically-latchable second control valve arranged in fluid communication between the actuating fluid common rail and the actuating fluid chamber of the exhaust valve, said second control valve selectively operable to move between i) a closed position at which the second control valve closes fluid communication between the actuating fluid common rail and the actuating fluid chamber of the exhaust valve and opens fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to be moved towards its closed position and ii) an opened position at which the second control valve opens fluid communication between the actuating fluid common rail and the actuating fluid chamber of the exhaust valve and closes fluid communication between the actuating fluid drain passage and the actuating fluid chamber of the exhaust valve thereby allowing the exhaust valve to be hydraulically moved towards its opened position

an electronically-controllable hydraulically-actuatable fuel injector extending into the combustion chamber and selectively operable to inject fuel therein, wherein said injector includes an actuating fluid chamber, a piston portion positioned in the actuating fluid chamber, a check valve movable between a closed position at which the check valve blocks injection of fuel and an opened position at

58

B

48 which the check valve opens injection of fuel, and an electronically-controllable  
49 magnetically-latchable third control valve arranged in fluid communication between  
50 the actuating fluid common rail and the actuating fluid chamber of the injector, said  
51 third control valve selectively operable to move between i) a closed position at  
52 which the third control valve closes fluid communication between the actuating fluid  
53 common rail and the actuating fluid chamber of the injector and opens fluid  
54 communication between the actuating fluid drain passage and the actuating fluid  
55 chamber of the injector thereby allowing the check valve of the injector to be moved  
56 towards its closed position and ii) an opened position at which the third control  
57 valve opens fluid communication between the actuating fluid common rail and the  
58 actuating fluid chamber of the injector and closes fluid communication between the  
59 actuating fluid drain passage and the actuating fluid chamber of the injector thereby  
60 allowing the check valve to be hydraulically moved towards its opened position,  
61 wherein said crankshaft is selectively rotatable in one angular direction and a reverse  
62 angular direction in response to selectable timing and sequence of operation of the  
63 intake and exhaust valves and the fuel injector relative to the position of the power  
64 piston.

44. A method of operating a two-stroke cycle power module having a  
rotatable crankshaft; an air compressor cell defining a variable-volume air  
compressor chamber, an air supply port, and an air exit port, said air supply port and  
air exit port each arranged in fluid communication with the air compressor chamber,  
said air supply port adapted to communicate with a source of supply air; an air  
supply valve associated with the air supply port and selectively operable to move  
between i) a closed position at which the air supply valve closes the air supply port  
and thereby closes fluid communication between the source of supply air and the air  
compressor chamber via the air supply port and ii) an opened position at which the  
air supply valve opens the air supply port and thereby opens fluid communication  
between the source of supply air and the air compressor chamber via the air supply  
port; an air pump piston positioned in the air compressor chamber and operable to  
move between i) an expansion position at which the air compressor chamber reaches  
its maximum volume and ii) a contraction position at which the air compressor

15 chamber reaches its minimum volume; a combustion cell defining a variable-volume  
16 combustion chamber separate from the air compressor chamber, an air intake port,  
17 and an exhaust port, said air intake port and exhaust port each arranged in fluid  
18 communication with the combustion chamber; an air storage chamber arranged in  
19 fluid communication between the air exit port of the air compressor cell and the air  
20 intake port of the combustion cell; an intake valve associated with the air intake port  
21 of the combustion cell and selectively operable to move between i) a closed position  
22 at which the intake valve closes the air intake port and thereby closes fluid  
23 communication between the air storage chamber and the combustion chamber via  
24 the air intake port and ii) an opened position at which the intake valve opens the air  
25 intake port and thereby opens fluid communication between the air storage chamber  
26 and the combustion chamber via the air intake port; an exhaust valve associated with  
27 the exhaust port of the combustion cell and selectively operable to move between i)  
28 a closed position at which the exhaust valve closes the exhaust port and thereby  
29 closes fluid communication between the combustion chamber and the exhaust port  
30 and ii) an opened position at which the exhaust valve opens the exhaust port and  
31 thereby opens fluid communication between the combustion chamber and the  
32 exhaust port; and a power piston positioned in the combustion chamber and coupled  
33 to the crankshaft for movement therewith, said power piston operable to move in the  
34 combustion chamber between i) an expansion position at which the combustion  
35 chamber reaches its maximum volume corresponding to a  $180^{\circ}$  angular position of  
36 the crankshaft and ii) a contraction position at which the combustion chamber  
37 reaches its minimum volume corresponding to a  $0^{\circ}$  angular position of the  
38 crankshaft, said method comprising the steps of:

39 moving the power piston from its contraction position and towards its  
40 expansion position;

41 opening the exhaust valve when the power piston has been moved to a first  
42 position corresponding to a first angular position of the crankshaft;

43 opening the intake valve when the power piston has been moved to a second  
44 position corresponding to a second angular position of the crankshaft;

45 moving the power piston to its expansion position;

60

B

46 moving the power piston from its expansion position and towards its  
47 contraction position;  
48 closing the exhaust valve when the power piston has been moved to a third  
49 position corresponding to a third angular position of the crankshaft;  
50 closing the intake valve when the power piston has been moved to a fourth  
51 position corresponding to a fourth angular position of the crankshaft; and  
52 moving the power piston to its contraction position.  
53

1 45. The method of claim 44, wherein the angular distance between the  
2 first and fourth angular positions is about 80°.  
3

1 46. The method of claim 44, wherein the first angular position of the  
2 crankshaft is about 140°, the second angular position of the crankshaft is about 160°,  
3 the third angular position of the crankshaft is about 200°, and the fourth angular  
4 position of the crankshaft is about 220°.  
5

1 47. The method of claim 44, wherein during operation of the power  
2 module the combustion chamber has a peak fluid pressure of about 13,790 kPa  
3 (about 2000 psi) when the power piston is at its contraction position.  
4

1 48. The method of claim 44, wherein during operation of the power  
2 module the combustion chamber has a residual fluid pressure greater than  
3 atmospheric pressure when the power piston is at its expansion position.  
4

1 49. The method of claim 48, wherein the residual fluid pressure in the  
2 combustion chamber is at least about 138 kPa (about 20 psi).  
3

1 50. The method of claim 48, wherein the residual fluid pressure in the  
2 combustion chamber is in the range of about 138 to 207 kPa (about 20 to 30 psi).  
3  
4  
5

61

B

1           51.    A power module, comprising:  
2                an actuating fluid compressor cell defining a variable-volume actuating fluid  
3   compressor chamber and an actuating fluid port arranged in fluid communication  
4   with the actuating fluid compressor chamber, said actuating fluid port adapted to  
5   communicate with a source of actuating fluid;  
6                an actuating fluid drain passage;  
7                an actuating fluid supply valve arranged in fluid communication between the  
8   source of actuating fluid and the actuating fluid port and selectively operable to  
9   move between i) a closed position at which the supply valve closes fluid  
10   communication between the source of actuating fluid and the actuating fluid  
11   compressor chamber via the actuating fluid port and ii) an opened position at which  
12   the supply valve opens fluid communication between the source of actuating fluid  
13   and the actuating fluid compressor chamber via the actuating fluid port;  
14                an actuating fluid pump piston positioned in the actuating fluid compressor  
15   chamber and operable to move therein between i) an expansion position at which  
16   the actuating fluid compressor chamber reaches its maximum volume and ii) a  
17   contraction position at which the actuating fluid compressor chamber reaches its  
18   minimum volume;  
19                a combustion cell defining a variable-volume combustion chamber, separate  
20   from the actuating fluid compressor chamber, an air intake port, an exhaust port, and  
21   an actuating fluid common rail, said air intake port and exhaust port each arranged in  
22   fluid communication with the combustion chamber;  
23                an actuating fluid storage chamber arranged in fluid communication between  
24   the actuating fluid port of the actuating fluid compressor cell and the actuating fluid  
25   common rail;  
26                an intake valve associated with the air intake port of the combustion cell and  
27   operable to move between i) a closed position at which the intake valve closes the air  
28   intake port and thereby closes fluid communication to the combustion chamber via  
29   the air intake port and ii) an opened position at which the intake valve opens the air  
30   intake port and thereby opens fluid communication to the combustion chamber via  
31   the air intake port;

62

B

32 an exhaust valve associated with the exhaust port of the combustion cell and  
33 selectively operable to move between i) a closed position at which the exhaust valve  
34 closes the exhaust port and thereby closes fluid communication between the  
35 combustion chamber and the exhaust port and ii) an opened position at which the  
36 exhaust valve opens the exhaust port and thereby opens fluid communication  
37 between the combustion chamber and the exhaust port; and

38 an electronically-controllable hydraulically-actuatable fuel injector extending  
39 into the combustion chamber and selectively operable to inject fuel therein, said fuel  
40 injector including an actuating fluid chamber, a piston portion positioned in the  
41 actuating fluid chamber, a check valve movable between a closed position at which  
42 the check valve blocks injection of fuel and an opened position at which the check  
43 valve opens injection of fuel, and an electronically-controllable fluid control valve  
44 arranged in fluid communication between the actuating fluid common rail and the  
45 actuating fluid chamber of the injector, said control valve selectively operable to  
46 move between i) a closed position at which the control valve closes fluid  
47 communication between the actuating fluid common rail and the actuating fluid  
48 chamber of the injector and opens fluid communication between the actuating fluid  
49 drain passage and the actuating fluid chamber of the injector thereby allowing the  
50 check valve of the injector to be moved towards its closed position and ii) an opened  
51 position at which the control valve opens fluid communication between the actuating  
52 fluid common rail and the actuating fluid chamber of the injector and closes fluid  
53 communication between the actuating fluid drain passage and the actuating fluid  
54 chamber of the injector thereby allowing the check valve to be hydraulically moved  
55 towards its opened position; and

56 a power piston positioned in the combustion chamber and operable to move  
57 therein between i) an expansion position at which the combustion chamber reaches  
58 its maximum volume and ii) a contraction position at which the combustion chamber  
59 reaches its minimum volume.

60  
1 52. The power module of claim 51, wherein said control valve is  
2 magnetically latchable in at least one of its closed and opened positions.  
3

63

B

1           53.     The power module of claim 51, further including a check  
2     valve arranged in fluid communication between the actuating fluid port of the  
3     actuating fluid compressor cell and the actuating fluid storage chamber, said check  
4     valve operable to allow only one-way fluid flow from the actuating fluid compressor  
5     chamber to the actuating fluid storage chamber.

1           54.     The power module of claim 51, wherein said actuating fluid supply  
2     valve includes a digitally-controlled two-way valve including a movable  
3     magnetically-latchable spool having one end portion and an opposite end portion, a  
4     closing-direction electrical coil located proximate the one end portion of the spool,  
5     and an opening-direction electrical coil located proximate the opposite end portion  
6     of the spool, said closing-direction electrical coil selectively operable to  
7     electromagnetically pull the spool towards one state corresponding to the closed  
8     position of the actuating fluid supply valve, said opening-direction electrical coil  
9     selectively operable to electromagnetically pull the spool towards another state  
10    corresponding to the opened position of the actuating fluid supply valve.

1           55.     The power module of claim 51, further including an electronic control  
2     unit operable to control the selectable operation of each said electronically-  
3     controllable valves.

1           56.     The power module of claim 55, further including an actuating fluid  
2     pressure sensor operable to i) sense the pressure of actuating fluid in the actuating  
3     fluid storage chamber and ii) provide the electronic control unit with an actuating  
4     fluid pressure signal indicative of said pressure, said electronic control unit operable  
5     to independently control the operation of the actuating fluid supply valve in response  
6     to said actuating fluid pressure signal.

1           57.     The power module of claim 51, wherein said injector is a multiple  
2     stage injector.

1           58.     The power module of claim 51, wherein said actuating fluid

64

B

2 storage chamber is integrally formed with the actuating fluid compressor cell.

3

1 59. The power module of claim 51, wherein said actuating fluid storage  
2 chamber is connected to the actuating fluid compressor cell.

3

1 60. The power module of claim 51, wherein said intake and exhaust  
2 valves each further include a return spring operable to bias the respective valve  
3 towards its closed position.

4

1 61. The power module of claim 51, wherein the actuating fluid  
2 compressor cell and the combustion cell are integrally formed with one another by a  
3 common housing.

4

1 62. The power module of claim 51, wherein the actuating fluid  
2 compressor cell and the combustion cell are connected together as a compact unit.

3

1 63. The power module of claim 51, wherein the actuating fluid pump  
2 piston and the power piston are movable by a common drive device.

3

65

B